

HUMAN CHOICE ON CONCURRENT VARIABLE-INTERVAL VARIABLE-RATIO SCHEDULES

ALAN SILBERBERG, JOHN R. THOMAS, AND NATASHA BERENDZEN

THE AMERICAN UNIVERSITY,
NAVAL MEDICAL RESEARCH INSTITUTE, AND
BOSTON UNIVERSITY

Each of 5 adult male humans sat in a 4 °C room where they could warm themselves by illuminating six heat lamps for 10-second periods according to a concurrent variable-interval variable-ratio schedule. Left-button presses on a response panel switched between the schedules and started a 2-second changeover delay. Right-button presses illuminated the heat lamps if assigned by the associated schedule and if the changeover delay had timed out. Panel lights identified the schedule in effect and each effective right-button press. A discrimination procedure—either a multiple variable-interval variable-ratio schedule or the presentation of each schedule individually on alternate days—preceded exposure to the choice procedure for some subjects. For subjects not exposed to a discrimination procedure prior to exposure to choice, or if such exposure failed to result in higher rates to the ratio than to the interval schedule, relative response rates matched relative reinforcement rates. However, if subjects responded at higher rates to the ratio schedule than to the interval schedule during a prior discrimination procedure, relative rates on a subsequent choice procedure deviated from matching in the direction of reinforcement-rate maximizing. In eight of 11 conditions, choice appeared to be governed by maximizing processes. In all cases, human concurrent ratio-interval performances differed from those of nonhumans in that matching was never obtained with local ratio-interval rate differences.

Key words: maximizing, matching, economics, choice, concurrent variable-interval variable-ratio schedule, heat reinforcement, button press, humans

In a study by Herrnstein and Heyman (1979), pigeons chose between a variable-interval (VI) and a variable-ratio (VR) schedule of food reinforcement. On this concurrent schedule, pigeons could maximize their rates of food reinforcement by responding mostly to the VR and switching to the VI only occasionally to obtain reinforcers assigned to that schedule. Instead, pigeons often preferred the VI schedule, sometimes exclusively. Although this result failed to maximize rates of reinforcement, VR choice ratios approximated VR reinforcement ratios—a result commonly called matching (Herrnstein, 1961). As a consequence of these and other findings in the choice literature, Herrnstein and Heyman concluded

that the matching law was likely to describe choice in nonhumans accurately in a wider range of choice procedures than was a reinforcement maximizing rule.

Implicit in this conclusion is the possibility that matching can also describe choice in humans more capably than can a maximizing rule. Indeed, Herrnstein (1990b) has made exactly this argument. As he notes, such a conclusion has wide theoretical import because it questions a primary assumption of economics—that human action is governed by a maximizing, not a matching, principle.

Although Herrnstein (1990b) musters several lines of evidence in support of his position, all are based on his claim that the primacy of matching over maximizing has been demonstrated in human and nonhuman operant choice experiments. We question this claim for two reasons. First, his arguments notwithstanding, it is not universally accepted that Herrnstein and Heyman (1979) demonstrated the primacy of matching over maximizing in nonhumans (Green, Rachlin, & Hanson, 1983; Sakagami, Hursh, Christensen, & Silberberg, 1989; Shurtleff & Silberberg, 1990; Ziriax & Silberberg, 1984; see, however, Heyman &

This research was supported by NSF grants, the U.S. Navy-ASEE Summer Faculty Research Program, and the Naval Medical Research and Development Command Research and Technology Work Unit, 63706N.M0096.002. The opinions and assertions contained herein are those of the authors and are not to be construed as official or reflecting the views of the Navy Department or the Naval Service at large. Address correspondence to A. Silberberg, Department of Psychology, The American University, Washington, D.C. 20016 (electronic mail via BITNET: asilber@auvm.american.edu).

Herrnstein, 1986). Second, even if the Herrnstein and Heyman (1979) report is viewed as showing that nonhumans match rather than maximize, there is danger in extending these conclusions to humans because schedule effects often differ between humans and nonhumans (e.g., Bentall, Lowe, & Beasty, 1985; Leander, Lippman, & Meyer, 1968; Lippman & Meyer, 1967; Logue, Peña-Correal, Rodriguez, & Kabela, 1986; Long, Hammack, May, & Campbell, 1958; Lowe, 1983; Lowe, Harzem, & Bagshaw, 1978; Lowe, Harzem, & Hughes, 1978; Weiner, 1969; Zeiler & Kelley, 1969).

A study by Catania, Matthews, and Shimoff (1982) is particularly relevant to this second point. In their experiment, humans' responses on a multiple random-ratio random-interval schedule were reinforced by points that could be exchanged for money. When instructed verbally to respond at high rates to the ratio schedule and at low rates to the interval schedule, rate differences consistent with instructions developed. However, when these instructions were not given, between-component rate differences often failed to emerge. This result is at variance with nonhuman performances under multiple VR VI schedules, in which ratio schedules consistently support higher rates than interval schedules do (e.g., Peele, Casey, & Silberberg, 1984; Silberberg, Warren-Boulton, & Asano, 1988).

This apparent phyletic difference in performance on multiple ratio-interval schedules raises the possibility that phyletic differences might also obtain on concurrent ratio-interval schedules. There are at least two possibilities as to what these differences might be. One possibility, suggested by Catania *et al.*'s (1982) findings, is that humans may often be insensitive to the contingency differences between ratio and interval schedules. This outcome, which would be reflected in equal local rates to the VR and the VI schedules, differs from Herrnstein and Heyman's (1979) finding that VR schedules support higher local rates in pigeons than do VI schedules. The second possibility is suggested by the descriptive successes of the maximizing assumption when applied to human consumers and the matching equation when applied to nonhuman concurrent-schedule performances: Perhaps humans will maximize reinforcement rates on concurrent VR VI schedules even though nonhumans might match.

These speculations were tested using a choice procedure with humans that was as similar as possible to that used with pigeons. Toward this end, we rejected a design based on reinforcing human responding with points that could be exchanged for goods or money. The problem with this arrangement is that the reinforcer occurs as a single event only at session's end. This circumstance differs in kind from food-maintained key pecking in pigeons, where reinforcement is delivered not at the end of the session but throughout it.

We remedied this problem by choosing as the reinforcer the brief delivery of heat to a cold subject. For cold humans, this stimulus directly and unconditionally maintains choice, just like food does in the hungry pigeon. Use of a heat reinforcer did, in our case, have its own problems: The temperature-controlled environment in which this study was conducted was available for only a few hours per day for 10 weeks. In consequence, the number of subjects and choice conditions had to be limited and conventional stability criteria bypassed.

Also taken into consideration in our design was the finding by Catania *et al.* (1982) that ratio-interval contingency differences in humans are often not mastered without prior discrimination training (also see Matthews, Shimoff, Catania, & Sagvolden, 1977). Therefore, some (but not all) subjects were given discrimination training either with multiple VR VI schedules or by alternating VR and VI schedules singly in successive sessions.

A final concern related to measurement: How should we determine whether a particular choice outcome was more compatible with a matching or maximizing prediction? Herrnstein and Heyman (1979) resolved this problem by comparing the data variance accommodated by the matching equation against that offered by their interpretation of the prediction of choice maximizing. Although they succeeded in quantifying a predictive difference, two problems, one explicit and one not, attended their approach. The explicit problem resided in their model's assumption that response and changeover probabilities do not change as a function of time since last occurrence. These assumptions are empirically in doubt (Houston, 1983; Silberberg & Ziriax, 1982). The implicit problem was that their model restricts maximizing effects to changes

in time allocation. If maximizing is reflected less in how subjects allocate time and more in the response and changeover rates Herrnstein and Heyman used as given, their model will fail to demonstrate maximizing tendencies in choice even if they are present.

Our solution to these problems was to abjure their goal of predicting the absolute difference in preference between a matching and maximizing subject. Instead, we compared maximizing against matching ordinally: If maximizing is present in choice, the relative rate of VR responding and VR time allocation should exceed the relative frequency of VR reinforcement. For this reason, we define maximizing in this study as a preference for the VR schedule greater than that predicted by matching.

METHOD

Subjects

Five male adults (S1 through S5) who passed a physical examination were paid \$12 per session to serve as subjects. They were informed about all health risks associated with cold environments and were assured they could quit the experiment at any time. A physician was in attendance throughout the experiment.

Apparatus

An intelligence panel (18 cm wide, 40 cm long, and angled at 45° from perpendicular) was located on a low table in an environmental chamber with temperature maintained at 4°C. Two lamps were located horizontally 3 cm apart on the left side of this panel. A push button was located 5 cm below the midline between this pair of lamps. A third lamp was located on the right side of the panel with a push button centered 5 cm below it. Beside the table was a stool surrounded by three wood towers, each of which supported two 250-W heat lamps. When these towers were placed around the stool in a manner typical of that selected by subjects, the operation of these lamps raised ambient temperature around the stool to approximately 15°C. A microcomputer that controlled the experiment was located underneath the table.

Procedure

Experimental contingencies. Each subject was exposed to one of two successive discrimination

procedures and a choice procedure. One discrimination procedure was a multiple VR VI 30-s schedule in which the size of the VR was adjusted in the first session after the completion of the first VR and VI components so that roughly equal reinforcement rates would be obtained under both schedules. Sessions began with equal probability with either the VR or the VI schedule. Thereafter, components and their associated schedules alternated every 12 reinforcers (10-s illuminations of the heat lamps). Left-side lamps, which sometimes differed in color (see Table 1 for each condition's assignments of lamp colors to schedules), distinguished between components. Each press of the right-side push button illuminated the right-side lamp with white light for 0.1 s and counted as a response to the schedule cued by the left-side lamp. During reinforcement, all lights on the response panel were extinguished, neither schedule operated, and button presses had no scheduled consequences. Sessions ended after 48 reinforcers or 40 min in the environmental chamber, whichever occurred first.

The second discrimination procedure used with some subjects differed from the regimen described above in one way: A component was presented singly throughout a session. Components alternated across successive sessions (Matthews et al., 1977), and sessions ended after 50 reinforcers or 40 min in the chamber, whichever occurred first.

The choice procedure was a concurrent VR VI 30-s schedule. For Subjects S3 and S5, VR-schedule values changed across conditions; for the others, a single-schedule VR value was used throughout the choice phase of the experiment. For Subject S4, a choice condition was interrupted during Sessions 12 through 15 to shape reinforced responding to both schedules. During choice, the left-side push button served as a changeover key, switching the left-side keylight color and the associated schedule of reinforcement. In addition, each changeover-key response initiated a 2-s timer. While this timer was in operation, VR or VI reinforcers available for a right-side button press were postponed until the first right-side response after the timer had terminated (2-s changeover delay or COD). Sessions ended after 50 reinforcers or 40 min in the chamber, whichever occurred first. Other contingencies were the same as in the discrimination procedures.

Table 1
Subjects, order of conditions, stimulus-schedule assignments and sessions per condition.

Subject	Procedure	VI lamp color	VR lamp color	Sessions
S1	VR 70 and VI	yellow	white	7
	30 s on alternate days			
	conc VI 30 s	yellow	white	4
S2	VR 70			
	conc VI 30 s	yellow	white	9
	VR 12			
	mult VI 30 s	yellow	white	7
S3	VR 25			
	conc VI 30 s	red	red	6
	VR 50			
	mult VI 30 s	red	red	5
	VR 50			
S4	conc VI 30 s	red	red	4
	VR 60			
	VR 70 and VI	yellow	white	8
	30 s on alternate days			
	conc VI 30 s	red	red	1
S5	VR 70			
	conc VI 30 s	red	red	17
	VR 70 (lamp-schedule assignments reversed)			
	VR 30 and VI	yellow	white	8
	30 s on alternate days			
	conc VI 30 s	yellow	white	7
	VR 30			
	conc VI 30 s	white	yellow	3
	VR 30			
	conc VI 30 s	white	yellow	4
	VR 45			
	conc VI 30 s	white	yellow	5
	VR 20			
	conc VI 30 s	white	yellow	7
	VR 60			

Subject numbers, the order of experimental conditions, the colors of the left VI and the right VR response-panel lamps, and the number of sessions a given condition was in effect are presented in Table 1.

Instructions to subjects. Subjects were required to enter the chamber wearing only socks, shorts, and an undershirt. After sitting for 10 min, they were seated at the stool and were invited to arrange the heating towers in any fashion they wished. Once this was done, the experiment was begun.

Before the subjects began responding in a discrimination procedure, they were told only to press the right-side button. They were also told that there would be "two arrangements for presenting heat to them, each signaled by the illumination of one of the left-side lamps." They were also told that heat presentation depended on pressing the right-side button. They

were given no information about the characteristics of the VR or the VI schedules.

The instructions for the choice procedure differed in that the subjects were told that pressing the left-side button would switch the light and the arrangement for heat presentation. They were also told that they could switch as frequently or as infrequently as they wished. Finally, they were told to have only one hand on the response panel at a time. They were given no information about the COD.

RESULTS

Table 2 presents the number of responses, seconds of time allocation, the number of reinforcers, and the number of changeovers during the last session of every choice condition for each subject for the VI and VR schedules.

Figure 1 presents, for S2 and S3, their rel-

Table 2
Unanalyzed data from the last session of each choice condition.

Subject	Choice condition	Responses		Times (s)		Reinforcers		Change-overs
		VI	VR	VI	VR	VI	VR	
S1	1	2,551	2,218	568	497	25	25	17
S2	1	231	319	177	252	19	31	29
S3	1	1,033	1,081	687	797	29	21	88
	2	617	1,956	292	459	19	31	59
S4	1	32	2,617	349	565	14	36	32
	2	182	2,726	41	561	10	40	22
S5	1	36	1,116	329	316	14	36	24
	2	47	1,159	410	330	13	37	30
	3	43	1,169	342	309	17	33	24
	4	27	1,095	184	310	9	41	27
	5	73	1,516	693	343	30	20	53

active rates of VI response, time allocation, and reinforcement throughout the experiment. Labels atop each identify the contingencies in effect for the functions presented below them. S2, who was exposed to a concurrent schedule followed by two different multiple schedules, showed no evidence in any condition of a higher local response rate to the VR than to the VI. During the choice condition, he had a small preference for the VR schedule, whereas during the multiple schedule he responded more to the VI.

Like S2, S3 showed little evidence of a VR-VI rate difference in the initial choice condition and had no apparent preference between choice schedules. This outcome changed following the emergence of discriminated rates during the multiple schedule condition (Sessions 7 through 11): During the next choice condition (Sessions 12 through 15), he showed, in terms of responses, a strong preference for the VR schedule over the VI, even though this outcome failed to match relative response rates to relative reinforcement rates. In terms of time allocation, his VR preference was less severe and resulted in approximate time-based matching.

Figure 2 presents the performances of 3 more subjects. In the left column are their response rates during the alternate discrimination procedure—that is, when VR and VI were presented singly for an entire session. Except for S1, these schedules alternated successively across sessions. These data show that S4 and S5 developed strong discriminative performances (rates much higher during VR than VI), whereas S1 did not. The right column

presents data from subsequent choice procedures. S1, who failed to discriminate the VR from the VI during the first seven sessions, preferred the VI to the VR in the choice condition and showed approximate matching.

The choice data of the other 2 subjects are at variance with this outcome. S4 (Figure 2) showed a powerful preference for the VR that violated matching predictions during his one session of exposure to concurrent VI 30 s VR 70. When these schedules were then reversed in the next two sessions, he failed to respond during the post-COD period, resulting in a failure to receive any VR reinforcement in Session 12. In consequence of this outcome, S4 received several sessions of training during which the COD value was gradually increased until he responded consistently past its 2-s threshold. In Session 16, he was returned to the concurrent VI VR schedule that had been postponed after Session 12. Across sessions, his choice shifted from matching with a VI-schedule preference to a strong VR-schedule preference incompatible with matching.

S5 was the only subject exposed to several different pairs of concurrent VI 30-s VR schedules. He consistently preferred the VR schedule and failed to match relative response rates and relative time allocations to relative reinforcement rates.

Figure 3 maps out the matching relation for all data segregated according to the following rule: If choice responding was preceded by different response rates to the VR and the VI during the last session of a discrimination procedure, the data from the last session of a given choice condition were placed in the bottom

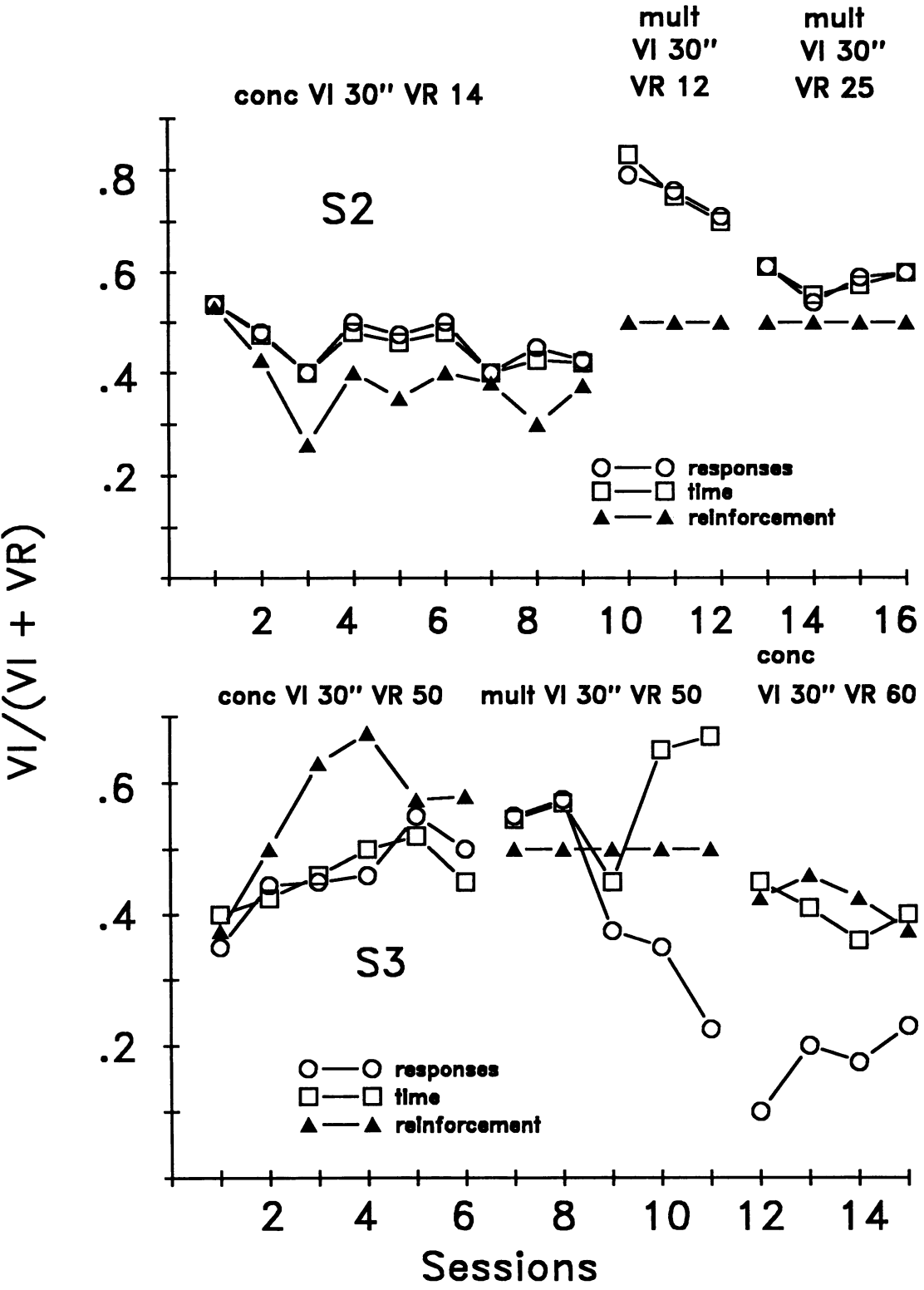


Fig. 1. Relative VI response rate, relative VI time allocation, and relative VI reinforcement for 2 subjects on concurrent and multiple schedule procedures.

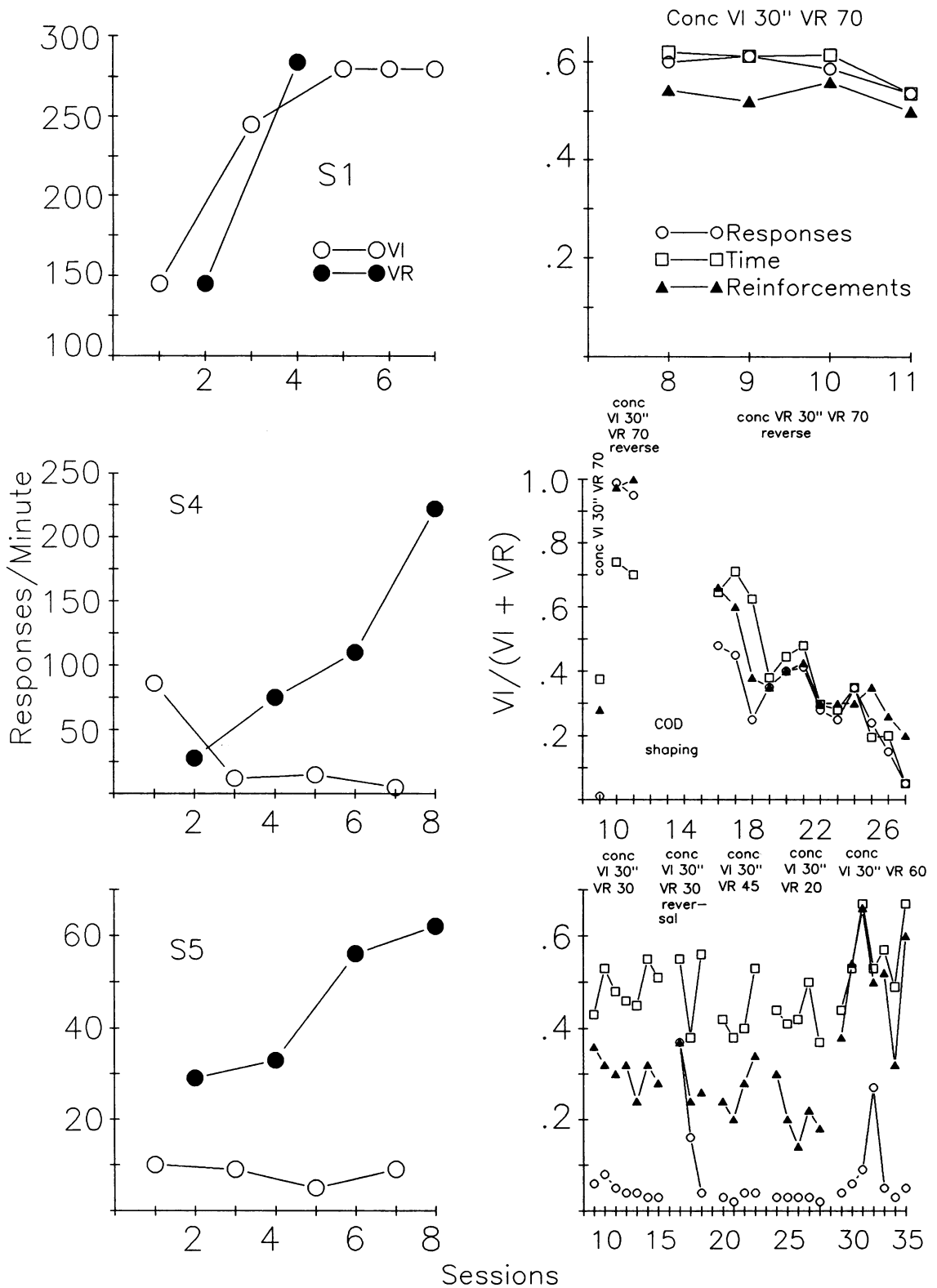


Fig. 2. Left panels present the response rate in responses per minute of 3 subjects when either a VI or a VR was presented singly during a session. Right panels present the relative VI response rate, VI time allocation, and relative VI reinforcement these subjects obtained during choice procedures (identified by labels at the top of the panels).

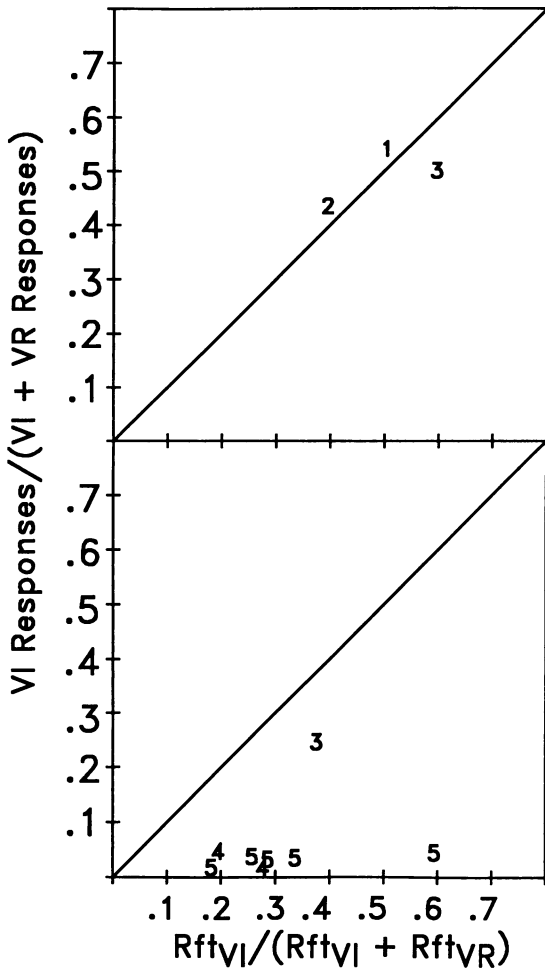


Fig. 3. Relative VI response rate as a function of relative VI reinforcement rate for all subjects. The diagonal defines the locus of perfect matching. Data in the top panel were not preceded by discriminative responding, whereas those in the bottom panel were. See text for other details.

panel; if VR and VI schedules during the preceding discrimination procedure supported nearly identical rates, or if the choice procedure was not preceded by a discrimination procedure, they were placed in the top panel. As is apparent from comparing these two panels, approximate matching was obtained when subjects failed to respond at different rates to the VR and the VI during the prior discrimination procedure; preference for the VR was greater than predicted by the matching equation when the choice conditions were preceded by differential VR-VI responding.

Figure 4 presents results of Figure 3 so as to quantify the judgment of whether a data point belonged in the top or bottom panel of Figure 3. Figure 4 shows the direction and size of the deviation from perfect response matching as a function of the direction and size of the VR-VI rate difference in a preceding discrimination procedure. If no discrimination procedure preceded choice, the VR-VI rate difference was zero. Closed circles are choice data points judged as not preceded by a discrimination procedure in which a representative VR-VI rate difference was obtained (see Catania *et al.*, 1982), whereas open circles define relative rates judged as following a discrimination procedure in which representative VR-VI rate differences were obtained. All data are based on the last session of a condition. These data suggest that a robust VR-VI rate difference in a discrimination procedure is a prerequisite for obtaining the matching-equation violations presented in Figures 3 and 4.

DISCUSSION

A series of papers by Herrnstein and his colleagues (Herrnstein, 1990a, 1990b; Herrnstein & Mazur, 1987; Heyman & Herrnstein, 1986) supports the following conclusions: (a) Although much of the literature on nonhuman choice is compatible with the predictions of both matching and maximizing models, a matching account is preferred because only it accounts for the finding that pigeons match rather than maximize on concurrent VI VR schedules; (b) despite the absence of concurrent VI VR data in humans, the finding of matching in human and nonhuman choice on concurrent VI VI schedules suggests there is no process difference among species in terms of their choice rule; and (c) therefore, one would expect that matching processes govern human choice, jeopardizing the microeconomic assumption that humans maximize utility.

In our view, all elements of the syllogism presented above exaggerate what can be prudently claimed by matching theorists. It is not yet accepted that maximizing is absent in choice on concurrent VI VR schedules (Green *et al.*, 1983; Sakagami *et al.*, 1989; Shurtleff & Silberberg, 1990). In fact, there is even debate as to whether a matching process is evident on these schedules (Zirias & Silberberg, 1984; see, however, Heyman & Herrnstein, 1986).

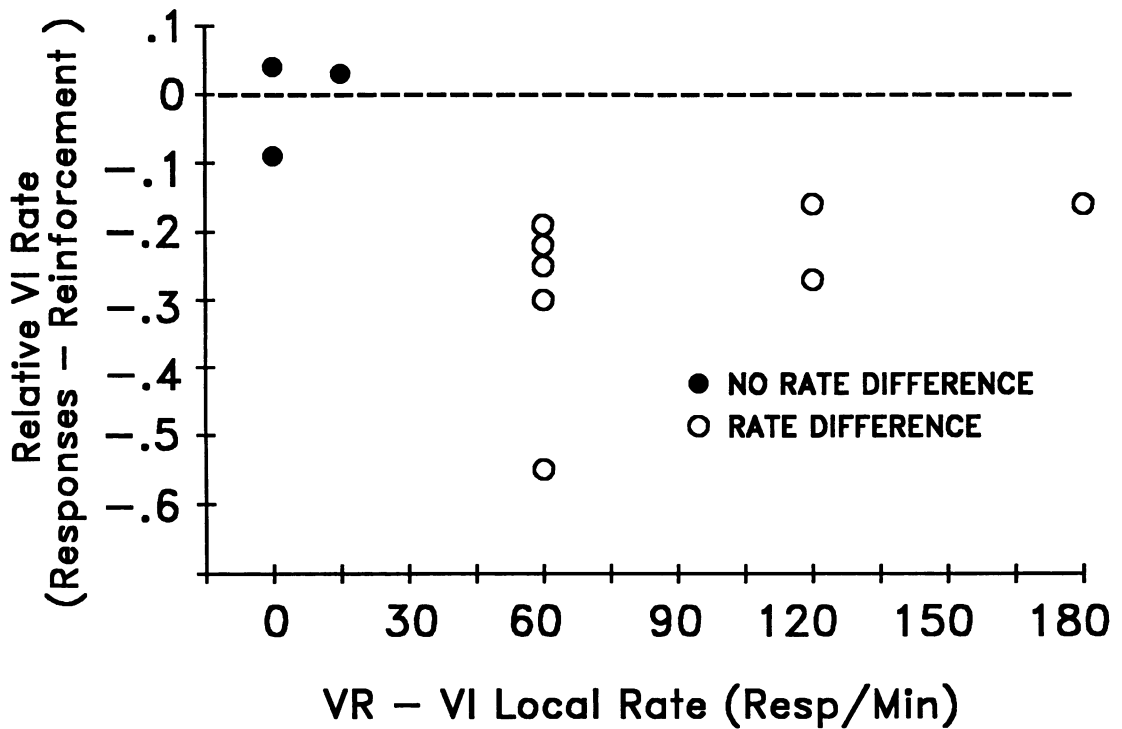


Fig. 4. Relative VI response rate minus the relative VI reinforcement rate as a function of the difference in response rate between the VR and VI schedules in a prior discrimination procedure. Dashed line is perfect matching. Points below the dashed line are deviations toward reinforcement-rate maximizing. See test for other details.

Even accepting the primacy of matching relations in nonhumans does not establish their primacy in humans, because, as noted earlier, there are many instances in which schedule effects differ phylogenetically. There is, in fact, little evidence contradicting the possibility that humans maximize even if pigeons match.

To date, only the present study has directly tested whether humans match or maximize in a choice procedure related to those used to evaluate whether nonhuman choice rules are optimal. In terms of relative response rates, three of 11 choice conditions were consistent with matching predictions, whereas the others deviated from matching in the direction of reinforcement-rate maximizing. These results establish that people, unlike pigeons, can and do maximize reinforcement rates on concurrent ratio-interval schedules. Of course, the results also show that sometimes humans match. However, a necessary condition for this matching was that human subjects *not* demonstrate the differential rates to ratio and interval schedules that inevitably are obtained

when these schedules reinforce pigeons' key pecks. In other words, only when humans fail to show the absolute VR-VI rate differences always found in pigeons do humans act like pigeons in matching on concurrent ratio-interval schedules. Without exception, these results establish that choice processes in humans differ from those in nonhumans on concurrent ratio-interval schedules.

These results do not support Herrnstein's (1990b) judgment that economics would be well served by replacing its assumption that humans maximize with one based on matching processes. On the contrary, this study's findings, when coupled with the many successes of economics (with its maximizing assumption) in characterizing human behavior and operant schedule effects (e.g., see Hastjarjo, Silberberg, & Hursh, 1990; Sakagami et al., 1989; Shurtleff & Silberberg, 1990; Shurtleff, Warren-Boulton, & Silberberg, 1987; Silberberg, Warren-Boulton, & Asano, 1987; Silberberg et al., 1988), suggest that economic models, methods, and reasoning continue to be

useful in explaining many features of behavioral output and choice in all subjects, be they human or not.

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Received December 26, 1990
Final acceptance March 24, 1991